PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 11 September 2000 (11.09.00)	
International application No. PCT/IB00/00156	**Applicant's or agent's file reference** W/D/123
International filing date (day/month/year) 15 February 2000 (15.02.00)	**Priority date** (day/month/year) 17 February 1999 (17.02.99)
Applicant SVOBODA, Jan	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

26 June 2000 (26.06.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Pascal Piriou

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
W/D/123		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/IB 00/ 00156	15/02/2000	17/02/1999
Applicant		
DE BEERS CONSOLIDATED MINES LIMITED et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [X] as suggested by the applicant.

   [ ] None of the figures.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International Application No
P[redacted]B 00/00156

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B03C1/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 336 980 A (UNION CARBIDE CORP) 29 July 1977 (1977-07-29) page 5, line 12 - line 38 page 10, line 1 -page 12, line 14; claims 1,2,6-9; figures 1-5	1,4-7
A	US 3 788 465 A (REIMERS G ET AL) 29 January 1974 (1974-01-29) column 3, line 66 -column 4, line 34; claim 1; figures 2,3	1,2,6,7
A	US 3 483 968 A (KAISER ROBERT) 16 December 1969 (1969-12-16) claims 1-3	1,2,5

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 April 2000	02/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Decanniere, L

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IB 00/00156

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR 2336980 A	29-07-1977	US 4062765 A	13-12-1977
		AU 2093376 A	29-06-1978
		CA 1074261 A	25-03-1980
		DE 2659254 A	30-06-1977
		JP 52084569 A	14-07-1977
		NL 7614501 A	01-07-1977
		ZA 7606958 A	26-10-1977
US 3788465 A	29-01-1974	NONE	
US 3483968 A	16-12-1969	GB 1232871 A	19-05-1971

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
W/D/123		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/IB00/00156	15/02/2000	17/02/1999
International Patent Classification (IPC) or national classification and IPC B03C1/32		
Applicant DE BEERS CONSOLIDATED MINES LIMITED et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
26/06/2000	18.05.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Stenger, M Telephone No. +49 89 2399 7353

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IB00/00156

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-8 as originally filed

Claims, No.:

1-7 as originally filed

Drawings, sheets:

1/6-6/6 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	2-3, 5-6
	No:	Claims	1, 4, 7
Inventive step (IS)	Yes:	Claims	
	No:	Claims	2-3, 5-6
Industrial applicability (IA)	Yes:	Claims	1-7
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

S ction V:

1.) Claim 1:
FR-A-2336980 discloses a ferrohydrostatic separation method in which a ferrofluid is used to separate materials of different density (p.1, l.1-10). A vertically oriented magnetic field (since the currents creating this magnetic field flow in a horizontal plane) is generated by open dipoles (see fig.3), comprising a vertical gradient (p.9, l.14-17 and l.27; p.5, equation 1), thereby implicitly controlling the apparent density of the ferrofluid. The magnet can be a permanent one or an electromagnet (p.10, l.11-12).

The subject-matter of claim 1 of the present application can not be considered as new according to article 33 (2) PCT, since all the features of claim 1 of the present application are disclosed in FR-A-2336980.

2.) Claim 7:
FR-A-2336980 also discloses an apparatus for separating materials having different densities (see fig.2). A separation chamber 21 is present into which the materials can be introduced at chute 24. Open dipoles are placed either in or adjacent to the chamber (p.11, l.27-31).

The subject-matter of claim 7 of the present application can not be considered as new according to article 33 (2) PCT, since all the features of claim 7 of the present application are disclosed in FR-A-2336980.

3.) Dependent Claims:
The features of claim 4 are also disclosed in FR-A-2336980 since it is implicit, that the magnetising coils 30 in fig.3 are designed such, that a required magnetic field pattern is achieved. Thus, it also can not be considered as new. The features of the other dependent claims, insofar as they are not known from the documents cited in the Search Report for the same purpose as in the present application, are generally known to a person skilled in the art, and therefore, do not produce an inventive step.

4.) Industrial applicability:
The industrial applicability of the invention is obvious.

S cti n VII:

1.) The new independent claims are not correctly limited against FR-A-2336980 as required by Rule 6.3(b).

2.) The relevant prior art known from FR-A-2336980 is not cited in the description (Rule 5.1(a)(ii) PCT).

3.) The description and the dependent claims are not adapted to the new independent claims (see Section VIII).

4.) No reference signs are comprised in the claims (Guidelines chapter III-4.11).

Section VIII:

1.) It is not clear, which unity of measurement is meant by 10-8**M** on p.1, second paragraph.

2.) The document ZA97/8598 cited on page 2 could not be retrieved by the search examiner.

3.) The references 34 and 42 cited on p.6 are not indicated in fig. 5 and 3, respectively, contrary to what is stated on p.6.

4.) In fig.6, the reference sign 36 appears to design the chamber for the ferrofluid, whereas in the first paragraph of p.7, this chamber is referenced 38.

5.) Fig.1 appears to show a prior art device. This is not explicitly stated in the description, which would make it clear that this figure does not show any embodiment of the invention.

6.) On p.6, in the last line of the first paragraph, it is not clear what is meant by "running cut of the gap".

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
B03C 1/32

A1

(11) International Publication Number: WO 00/48740

(43) International Publication Date: 24 August 2000 (24.08.00)

(21) International Application Number: PCT/IB00/00156

(22) International Filing Date: 15 February 2000 (15.02.00)

(30) Priority Data:
99/1255 17 February 1999 (17.02.99) ZA

(71) Applicant *(for all designated States except US)*: DE BEERS CONSOLIDATED MINES LIMITED [ZA/ZA]; 36 Stockdale Road, 8301 Kimberley (ZA).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: SVOBODA, Jan [ZA/ZA]; 158 Cornelis Street, 2195 Fairland (ZA).

(74) Agents: BROWN, Keith, Edwin, Frank et al.; Spoor and Fisher, Rochester Place, 173 Rivonia Road, Morningside, Sandton, P.O. Box 41312, 2024 Craighall (ZA).

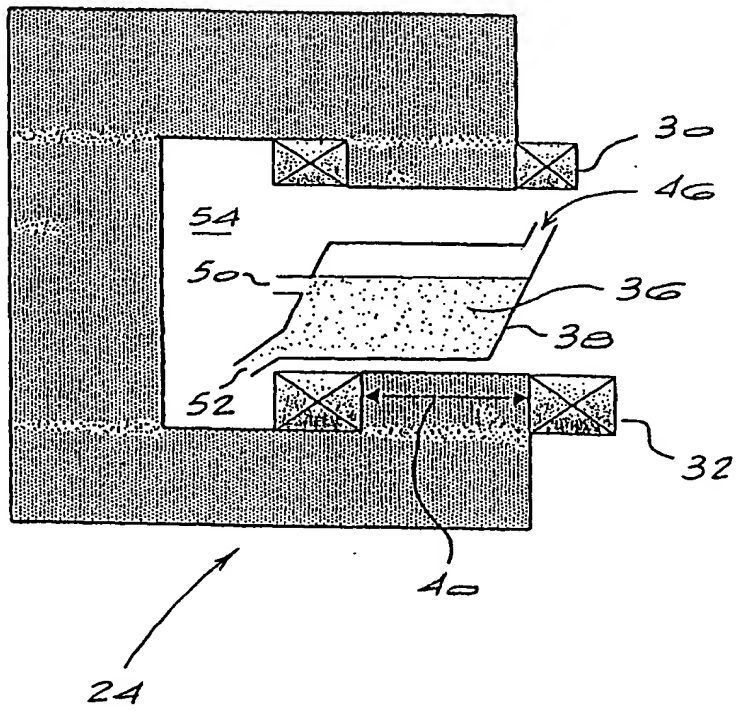
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: FERROHYDROSTATIC SEPARATION METHOD AND APPARATUS

(57) Abstract

The invention concerns, in one aspect, a ferrohydrostatic separation method in which a ferrofluid is used to separate materials of different density. In the method, the apparent density of the ferrofluid is controlled by means of a vertically orientated magnetic field generated by a C-dipole, open dipole (O-dipole) or split pair electromagnet or permanent magnet. Other aspects of the invention include an apparatus for use in this method and a process for separating materials of different density using the method.



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FERROHYDROSTATIC SEPARATION METHOD AND APPARATUS

BACKGROUND TO THE INVENTION

THIS invention relates to a ferrohydrostatic separation (FHS) method and apparatus.

As defined in the specification of US patent 3,483, 969, a ferrofluid is a material comprising a permanent, stable suspension of ferromagnetic material in a suitable liquid carrier. A common ferrofluid comprises fine particles typically 10-8M or less in size) of magnetite in a liquid. In this case, the extremely fine nature of the particles maintains them indefinitely in suspension without sinking or agglomerating.

The use of a ferrofluid to separate materials of different densities, referred to in the art as ferrohydrostatic separation (FHS), is also known and is, for instance, described in the specification of US patent 3,483,969. The materials which are to be separated can be solid particulate materials or liquids which are immiscible with the carrier liquid of the ferrofluid. In essence, the separation process involves applying a magnetic field of a specific pattern to the ferrofluid with a view to controlling the apparent density of the ferrofluid within close limits. The materials which are to be separated are then deposited in the ferrofluid. with the result that those materials which have a density exceeding the controlled apparent density of the ferrofluid will sink in the ferrofluid while those which have a density less than

that of the ferrofluid will float in the ferrofluid. The sink and float fractions can then be recovered separately.

In all known prior art FHS separators using ferrofluids and employing electromagnets or permanent magnets with an iron yoke, the magnetic field of a specific pattern is generated in a horizontal direction with the ferrofluid situated between the pole tips of the magnet. This arrangement has the significant disadvantage that in order to achieve a magnetic field across a suitably large volume to enable the FHS technique to be used for large material throughputs, it is necessary to increase the gap between the pole tips of the magnet. This in turn results in a large and uneconomical increase in the volumes of copper and iron required to construct the magnet and, in general, in the overall size and mass of the separation apparatus. In addition, the arrangement does not lend itself to large scale-up to treat large tonnages of material.

To overcome these limitations of the conventional iron yoke-based design with a horizontally orientated magnetic field, the specification of South African patent ZA 97/9598 proposes an arrangement in which a magnetic field with specific pattern is generated in a vertical direction by means of a solenoid, typically with a ncn~uniform winding. The use of a solenoid has numerous advantages compared to the use of an iron yoke electromagnet or permanent magnet, these being set out in the aforementioned patent specification. For instance, with a solenoid it is possible to increase the throughput merely by increasing the relevant transverse dimension of the solenoid, the axial length of the air gap remaining constant.

Although the solenoid-based proposal described in the aforementioned patent specification provides the ability to scale up the FHS technique to treat large volumes of material, the relative complexity of the winding design and of the steel cladding, together with the necessity to generate a rather high magnetic field in order to achieve the desired field pattern, are inherent disadvantages. Since a modest magnetic field strength is generally required in the FHS technique these drawbacks can, however be countered by taking advantage of the high saturation magnetisation of steel.

Another disadvantage of the conventional iron yoke FHS systems is the fact that the gradient of the magnetic field is proportional to the magnetic field strength. In order to achieve a low apparent density of the ferrofluid, for example to separate low-density materials such as coal, low magnetic field gradient and field strength are required. However the field may then be unable to retain the ferrofluid in the separation gap, necessitating complicated mechanical means to prevent the ferrofluid from running cut of the gap.

SUMMARY OF THE INVENTION

According to the present invention the apparent density of a ferrofluid used in an FHS technique is controlled by a vertically orientated magnetic field generated by a C-dipole, open dipole (O-dipole) or split pair electromagnet or permanent magnet.

The required magnetic field pattern in the vertical direction, for example including constant magnetic field gradient, can be achieved in the case of a C-dipole electromagnet by appropriate design of the magnetising coils on upper and lower legs of the C-dipole and/or by controlling the relative polarity of electrical current flowing through these coils and/or by appropriate shaping of the C-dipole tips.

In the case of a split pair electromagnet, the required magnetic field pattern in the vertical direction, for example including a constant magnetic field gradient, can be achieved by appropriate design of the magnetising coils on upper and lower members of the split pair and/or by controlling the relative polarity of electrical current flowing through these coils and/or by appropriate shaping of the tips of the upper and lower members.

The required magnetic field pattern in the vertical direction, for example a constant magnetic field gradient, can be achieved in the case of an O-dipole electromagnet by appropriate shaping of the steel core of the magnet and/or by appropriate design of the magnetising coil.

Another aspect of the invention provides a method of separating materials of different density comprising introducing the materials into a ferrofluid, using a C-dipole, O-dipole or split pair magnet to generate a magnetic field to control the apparent density of the ferrofluid to a value between the densities of the materials, and separately recovering materials which sink and float therein.

Still further according to the invention there is provided a ferrohydrostatic separation apparatus for separating materials having different densities, the apparatus including a separation chamber for accommodating a ferrofluid into which the materials can be introduced, and a C-dipole, O-dipole or split pair magnet adjacent the chamber for generating a magnetic field to control the apparent density of the ferrofluid.

The use of a C-dipole, O-dipole or split pair magnet has several advantages when compared to the use of a conventional iron yoke electromagnet or permanent magnet, as follows:

1. As explained above, the throughput in the conventional system requires the gap between the pole tips to be increased. However with a C-dipole, O-dipole or split pair magnet system as proposed by this invention, throughput can be increased merely by increasing the length of the magnet, leaving the air gap between the pole tips constant. Because the number of ampere-turns required to generate a given magnetic field is dependent on the air gap, which remains constant in C-dipole, O-dipole and split pair configurations, it is possible to scale up a C-dipole, O-dipole or split pair magnet to any practical size while keeping the number of ampere-turns constant.

2. The magnetic field along the length of a C-dipole, O-dipole or split pair magnet is homogeneous. Thus the same magnetic field pattern and apparent ferrofluid density can be maintained along the full length of the magnet, and that full length can be used for separation purposes, resulting overall in a more compact separator.

3. Because a rather low magnetomotive force is required to magnetically saturate mild steel and the saturation magnetisation of mild steel is high, the magnetic field strength at the pole tips of a C-dipole, O-dipole or split pair magnet can be considerably greater than in the working gap of the iron yoke magnet used in conventional FHS systems. It is accordingly possible to use a more diluted ferrofluid having a lower density and magnetisation. This can lead to a reduction in ferrofluid costs, and it is envisaged that the efficiency of the separation process can improve as a result of the reduced viscosity of the more dilute ferrofluid.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Figure 1 shows an electromagnet 10 which includes windings 12 arranged about the limbs 14 of an iron yoke 16 having pole tips 18. A working space 20 is defined between the pole tips 18. As indicated by the arrow, a horizontally orientated magnetic field is generated between the pole tips 18 which, at the same time, generate a vertically orientated magnetic field gradient.

In a conventional FHS separation system employing a magnet 10 of this type, a ferrofluid, typically a suspension of fine magnetite particles in stable suspension in a suitable liquid, is located in the working space 20 between the pole tips. The apparent density of the ferrofluid is controlled to a desired value by ensuring that the magnetic field gradient is kept at least approximately constant. The surfaces 22 of the pole tips must be carefully designed to ensure that the magnetic field gradient is as constant as possible.

Materials which are to be separated into fractions of different density respectively greater and less than the controlled apparent density of the ferrofluid are introduced into the ferrofluid, with the result that the denser particles sink while the less dense particles float.

As described above, in order to treat large throughputs of material, the gap between the pole tips must be increased, resulting in an increase in the volumes of iron and copper required to construct the magnet, in the energy required to

generate the magnetic field and in the overall size and mass of the separator. These increases limit the practical scale-up of the separator so that only modest throughputs can be treated using separators based on this conventional magnet design.

Reference is now made to Figures 2 to 6, illustrating embodiments of the present invention in which the conventional iron yoke magnet is replaced by a C-dipole, O-dipole (open-dipole) or split pair magnet with a mild steel core, and which are capable of separating materials at high throughput rates. Figures 2 and 3 illustrate a C-dipole magnet 24, Figures 4 and 5 illustrate an O-dipole magnet 26 and Figure 6 illustrates a split pair magnet according to the invention.

In each case, the magnet generates a vertically orientated magnetic field which has a natural gradient since the field strength is greatest on the surface of the pole tips 28. By judicious design of the windings 30 and 32 in Figures 2 and 3 and in Figure 6, and 34 in Figures 4 and 5, and by appropriate adjustment of the relative polarities of the electric current flowing in the coils it is possible to adjust the vertically orientated magnetic field gradient so that it is constant in a volume 36 of ferrofluid accommodated in a separation chamber 38.

The width 40 of the pole tips in each case is determined by the width of the separation chamber 38 which is in turn determined by the required residence time in the ferrofluid of the material which is to be separated. In Figures 2 and 3 and in Figure 6, the vertical distance 42 between the pole tips 28 is determined mainly by the vertical dimension of the chamber 38. In these embodiments, the overall length 44 of the magnet determines the throughput of the separator, and can be made as great as is practically feasible to give the required throughput. The dimensions 40 and 42, and hence the magnetomotive force required to generate the required magnetic field, are the same irrespective of the dimension 44 and accordingly of the throughput of the separator. In a typical example, the dimensions 40, 42 and 44 may be 400mm, 300mm and 1 metre (or more) respectively.

Feed material 46 is introduced into the chamber 38, typically by means of a vibratory feeder, along the entire length 44 of the magnet 24, 26. In the embodiment of Figures 2 and 3 the feed material can be introduced into the ferrofluid either from the outside, as indicated in Figure 3, or through openings (not illustrated) in the wall 48 of the magnet structure. In Figure 6 the chamber 38 is shown in particularly diagrammatic form but it will be understood that it could have a form similar to that shown in the other Figures.

As is conventional in the FHS technique, particles in the feed material which have a density less than the apparent density of the ferrofluid, as controlled by the magnetic field, will float in the ferrofluid and report to an elevated outlet 50. Particles which have a density exceeding the apparent density of the ferrofluid sink through the ferrofluid and are withdrawn through a lower chute 52. Both float and sink fractions are withdrawn continuously.

In Figures 2 and 3 the fractions can, for example, be removed on respective conveyor belts or other transport systems moving in the space 54 defined between the arms of the C-dipole magnet 24. In situations where this would be impossible because the feed material is introduced through openings in the wall 48, suitable transport systems could operate on the opposite side of the separation chamber 38.

It will be understood that in the O-dipole configuration of Figures 4 and 5 and the split pair configuration of Figure 6, the geometry of the magnet structure imposes less limitations on the positioning of the feed introduction and separated fraction withdrawal systems.

Mention was made above of the disadvantages faced by conventional iron yoke FHS systems when dealing with low density materials such as coal. However in the C-dipole, O-dipole and split pair arrangements proposed by the present invention, the magnetic field is able to hold magnetically diluted ferrofluid suitable for low density applications even at the low magnetic field gradients required to achieve separation.

It is also recognised that in conventional iron yoke FHS systems, the range of apparent densities which can be achieved with a given design of the magnetic circuit and pole tip profile is rather limited. In the C-dipole and split pair configurations proposed by the present invention, however, the magnetic field gradient and thus the apparent density of the ferrofluid can be varied widely by adjusting the electrical currents and the polarities thereof, flowing through the upper and lower windings 30 and 32. It is envisaged that apparent densities as a high as 25 gcm^{-1} could be achieved using a single C-dipole or split pair separator.

Although specific reference has been made to the use of a C-dipole, O-dipole or split pair electromagnet, the use of a C-dipole, O-dipole or split pair permanent magnet is within the scope of the invention. In these cases, variation of the apparent density of the ferrofluid is achieved by appropriate design of the core of the magnet and/or the shape of the pole tips.

CLAIMS

1.

A ferrohydrostatic separation method in which a ferrofluid is used to separate materials of different density, the method comprising the step of controlling the apparent density of the ferrofluid by means of a vertically orientated magnetic field generated by a C-dipole, open dipole (O-dipole) or split pair electromagnet or permanent magnet.

2.

A method according to claim 1 wherein a required magnetic field pattern in the vertical direction is achieved, in the case of a C-dipole electromagnet, by appropriate design of the magnetising coils on upper and lower legs of the Cdipole and/or by controlling the relative polarity of electrical current flowing through these coils and/or by appropriate shaping of the C-dipole tips.

3.

A method according to claim 1 wherein a required magnetic field pattern in the vertical direction is achieved, in the case of a split pair electromagnet, by appropriate design of the magnetising coils on upper and lower members of the split pair and/or by controlling the relative polarity of electrical current flowing through these coils and/or by appropriate shaping of the tips of the upper and lower members.

4.

A method according to claim 1 wherein a required magnetic field pattern in the vertical direction is achieved, in the case of an O-dipole electromagnet, by appropriate shaping of the steel core of the magnet and/or by appropriate design of the magnetising coil.

5.

A method according to any one of claims 2 to 4 wherein the required magnetic field pattern includes the provision of a constant magnetic field gradient.

6.

A method of separating materials of different density comprising introducing the materials into a ferrofluid, using a C-dipole, O-dipole or split pair magnet to generate a magnetic field to control the apparent density of the ferrofluid to a value between the densities of the materials, and separately recovering materials which sink and float in the ferrofluid.

7.

A ferrohydrostatic separation apparatus for separating materials having different densities, the apparatus including a separation chamber for accommodating a ferrofluid into which the materials can be introduced, and a C-dipole, O-dipole or split pair magnet adjacent the chamber for generating a magnetic field to control the apparent density of the ferrofluid.

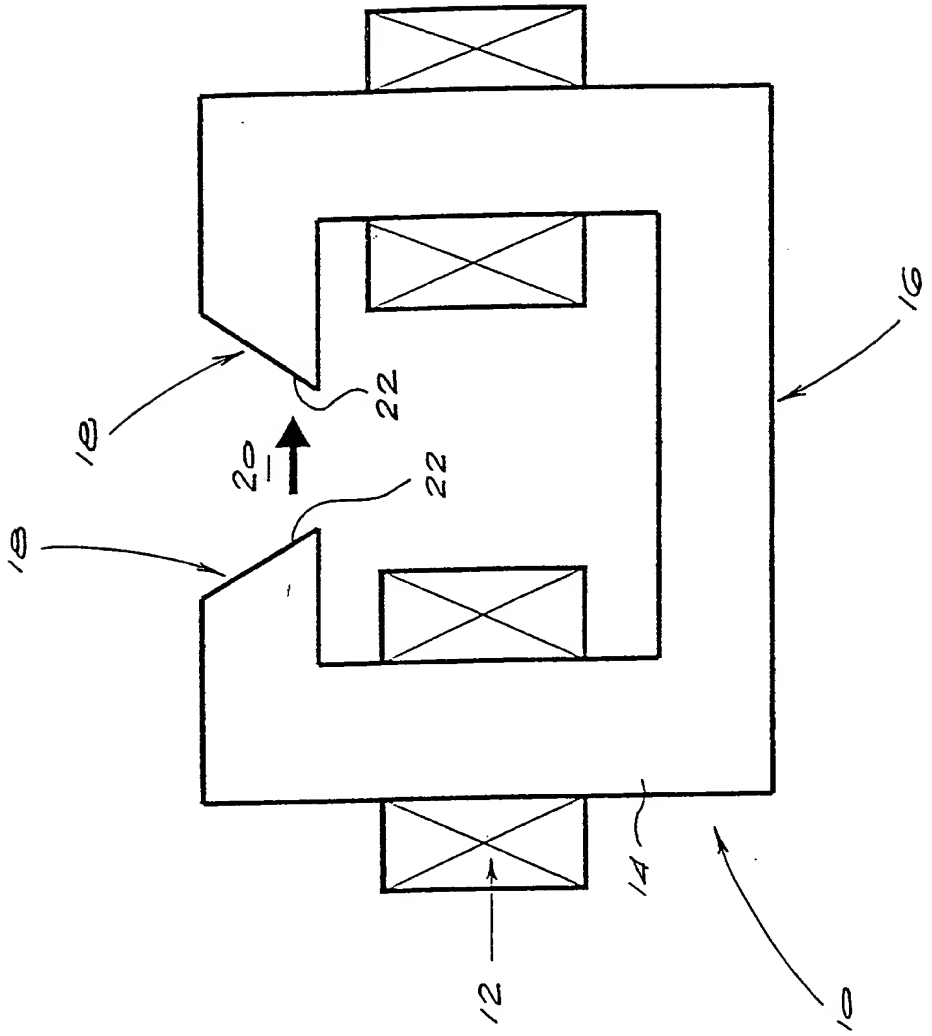

Fig 1

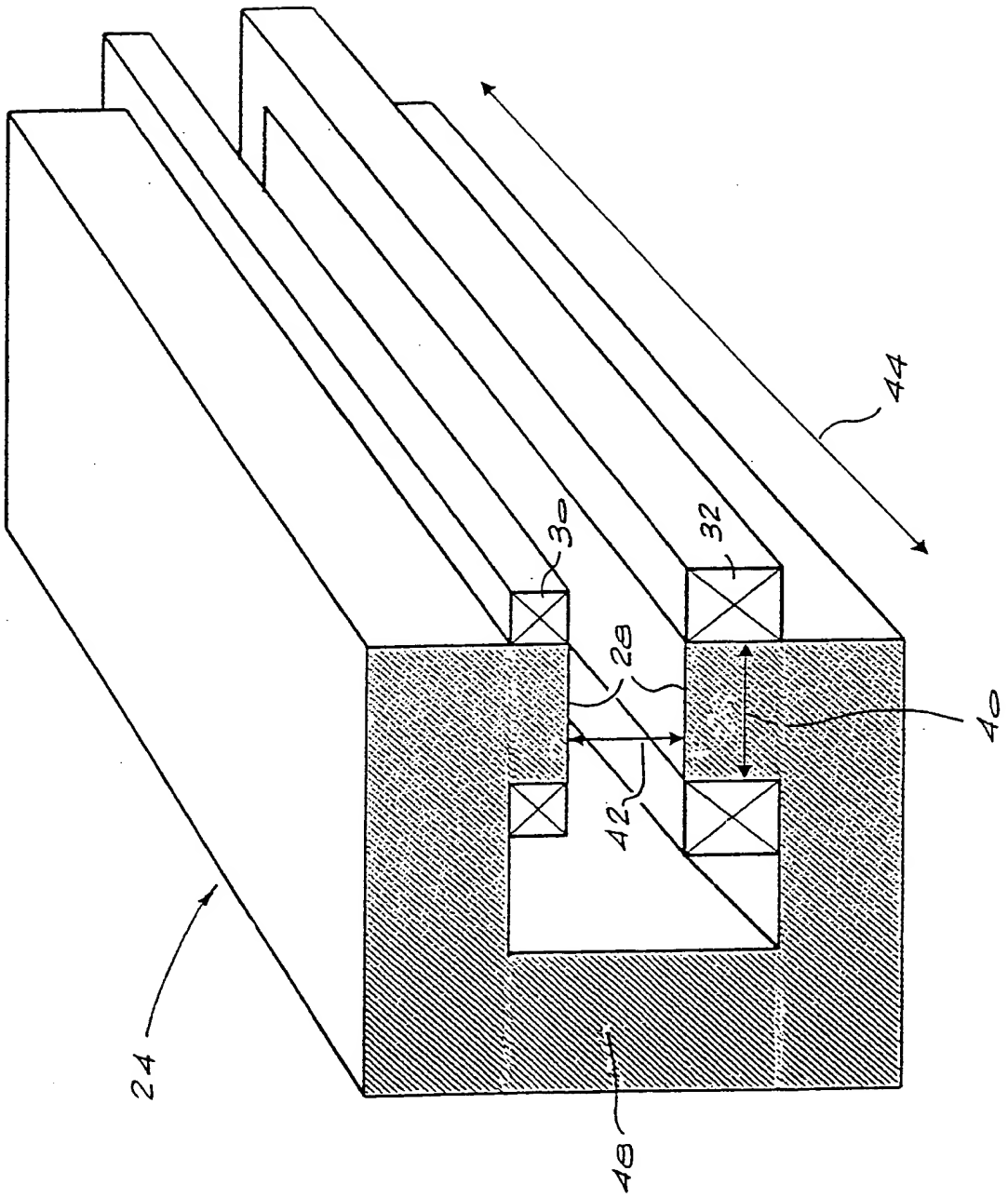

FIG 2

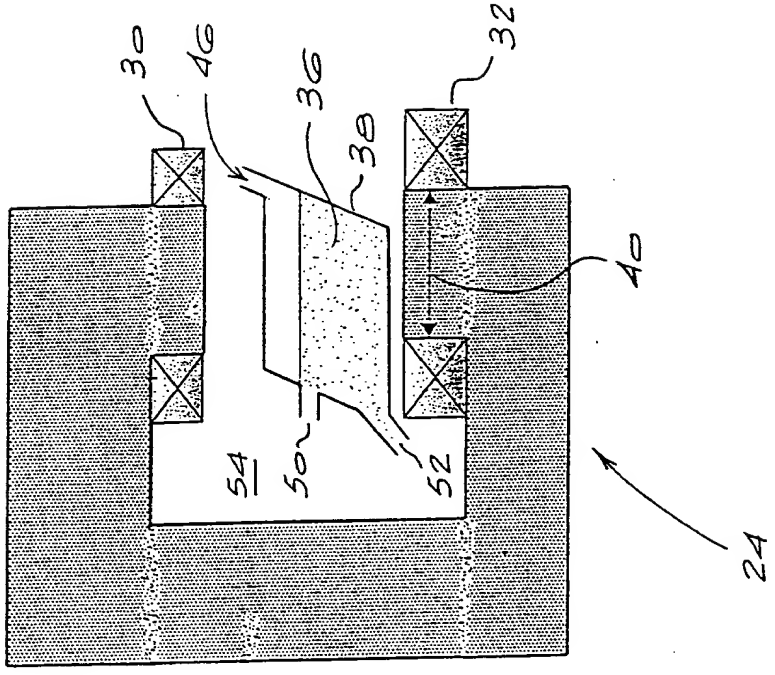

Fig 3

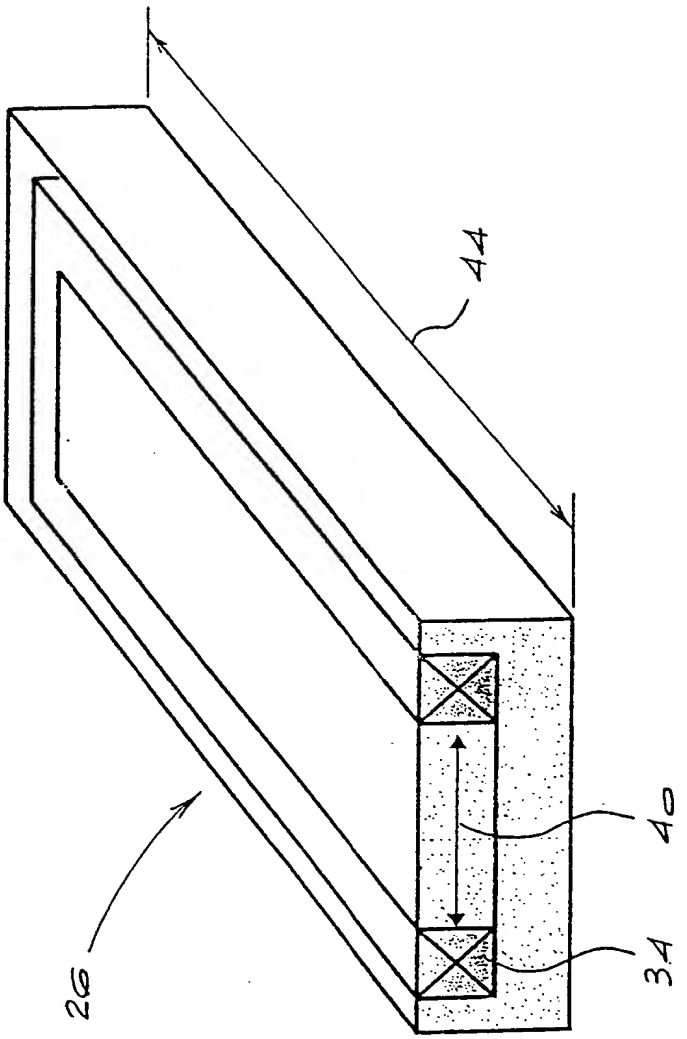

Fig 4

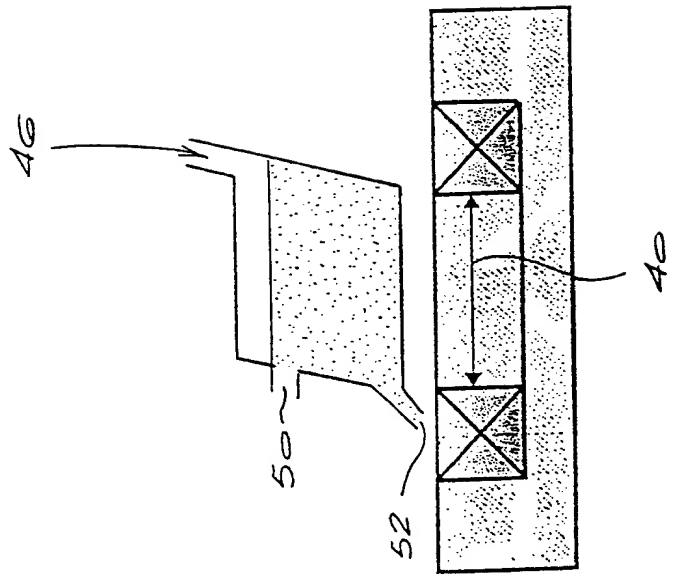

Fig 5

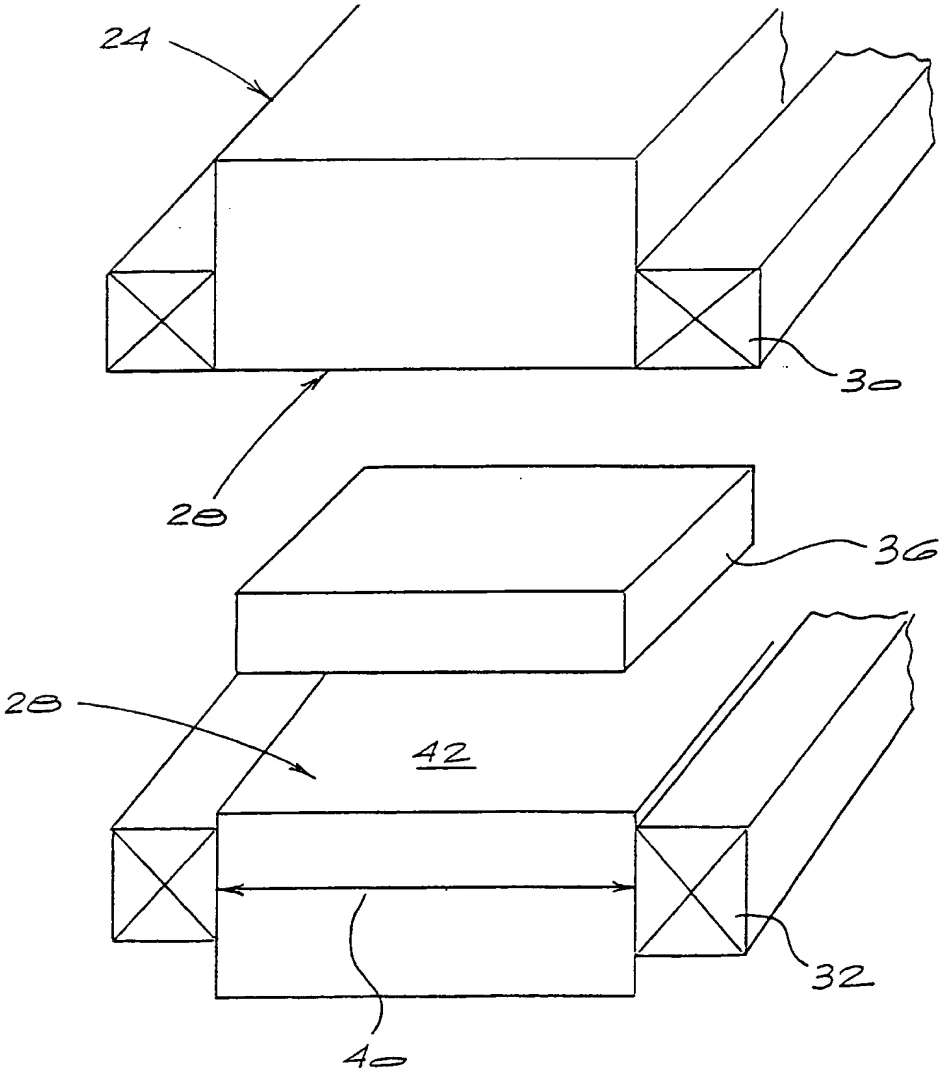

Fig 6